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Small-Scale Variations in CD Strips Observed Using Ultrasonic Velocity Measurements

M.S. Hall and T.G. Jackson

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SMALL-SCALE VARIATIONS IN CD STRIPS OBSERVED USING ULTRASONIC VELOCITY MEASUREMENTS

Maclin S. Hall and Theodore G. Jackson
Institute of Paper Science and Technology
Atlanta, GA 30318-5794 - USA

Abstract: The velocity of ultrasound may be used as a measure of the specific elastic stiffnesses, i.e., (Ultrasound Velocity)^2 = Elastic Stiffness / Density. In-plane and thickness-direction (ZD) ultrasonic velocity measurements and basis weight measurements are made at cross-direction (CD) intervals as small as 1 millimeter on CD strips in the laboratory. These measurements show large short-range variations in the properties of typical machine-made paper samples.

The measurement equipment and procedures are described. Data for typical cross-direction strips is presented and the repeatability of the measurements demonstrated. The measured short-range variations in CDstrip properties may be related to the streaks and "dry-line fingers" observed on the forming table.

Keywords: CD strip, variations, measurement

INTRODUCTION

In-plane and thickness-direction (ZD) ultrasonic velocity measurements and high resolution basis weight measurements show large short-range variations in the properties of typical machine-made paper. Measurements of the velocities of ultrasound provide nondestructive means to determine the specific stiffnesses of paper, i.e., (Ultrasound Velocity)^2 = Elastic Stiffness / Density. In-plane measurements can be made on cross-direction (CD) strips at intervals as small as 1 millimeter.

The transit time and velocity of ultrasound in the thickness direction (ZD) are measured by mounting CD strips spliced as part of a 12-meter belt on the IPST web handling system. Using transducers mounted in fluid-filled wheels, the transit time of ultrasound through the thickness of the paper can be determined 50 times a second. This provides a reading at 5-millimeter intervals for a sample moving at 15 meters per minute.

Hardware and software have been developed to collect measurement data at a high sampling rate directly from the sensors in an AccuRay® 1190™ System with a Smart Platform™ 1200 that is installed on the IPST web handling system. For a sample moving at 15 meters per minute, a sampling rate of 250 measurements per second provides a basis weight reading every millimeter. The measurement equipment and procedures are described. Data and repeatability of the measurements for typical cross-direction strips are presented.

ROBOT-BASED IN-PLANE INSTRUMENT

The in-plane measurement system uses a set of two wideband bimorph bender ultrasonic transducers [1]. A robot (an Adept 604-S four-axis robot) with a special holder for the transducers can be programmed to orient and position the transducers for the desired measurements. One transducer serves as a transmitter, excited at 80 kHz, and the other serves as the receiver. The receiver is positioned first at a NEAR distance (typically 2.5 cm) and then at a FAR position (typically 7.5 cm from the transmitter). The measured difference in the pulse flight time is determined by cross correlation of the pulses received in the NEAR and FAR positions. The in-plane velocity is calculated by dividing the path length difference by the measured difference in the pulse flight time. The transducers may be oriented to operate in the longitudinal or shear mode and aligned in the machine direction (MD), the CD, or other angular orientations.

In-plane measurements on CD strips are usually made at 5- or 10- cm intervals with polar readings every 15 degrees. However, with the interest in short-range variations of cross-machine properties, the possibility of making higher resolution in-plane measurements was examined. Direct measurement of the CD longitudinal velocity would require a transducer spacing of several centimeters, thus limiting the resolutions of short-range variations. However, if one uses the relationship [2]

$$(V_{SH})^2 = 0.387\,(V_{MD})(V_{CD}), \qquad (1)$$

it is only necessary to measure the MD longitudinal velocity (V_{MD}) and the shear velocity (V_{SH}) to determine a value for the CD longitudinal velocity (V_{CD}). Because the shear velocity (V_{SH}) is the same whether measured in CD or MD, both the longitudinal velocity and the shear velocity are measured in the MD, and the CD longitudinal velocity is calculated using the above relationship,

$$V_{CD} = 2.58\,(V_{SH})^2/V_{MD}. \qquad (2)$$

The robot can be programmed to align the transducer pair in the MD and increment the position of the transducers in steps as small as 1 millimeter along the CD of a CD strip. Figure 1 presents MD specific stiffness data for a segment of a CD strip determined by measuring the MD longitudinal velocity at 1-millimeter intervals by this procedure.

The application of Equation 2 is presented in Figure 2. MD longitudinal velocity and MD shear velocity were measured at 2-millimeter intervals along an entire CD strip of 80 g/m^2 kraft. The CD longitudinal velocity was calculated using Equation 2. Data are presented in Figure 2 for a 1-meter segment of this CD strip. The MD longitudinal velocity measurements at 2-millimeter intervals along the CD strip were repeated. These data are also plotted in Figure 2 to demonstrate the repeatability of the MD velocity measurements.

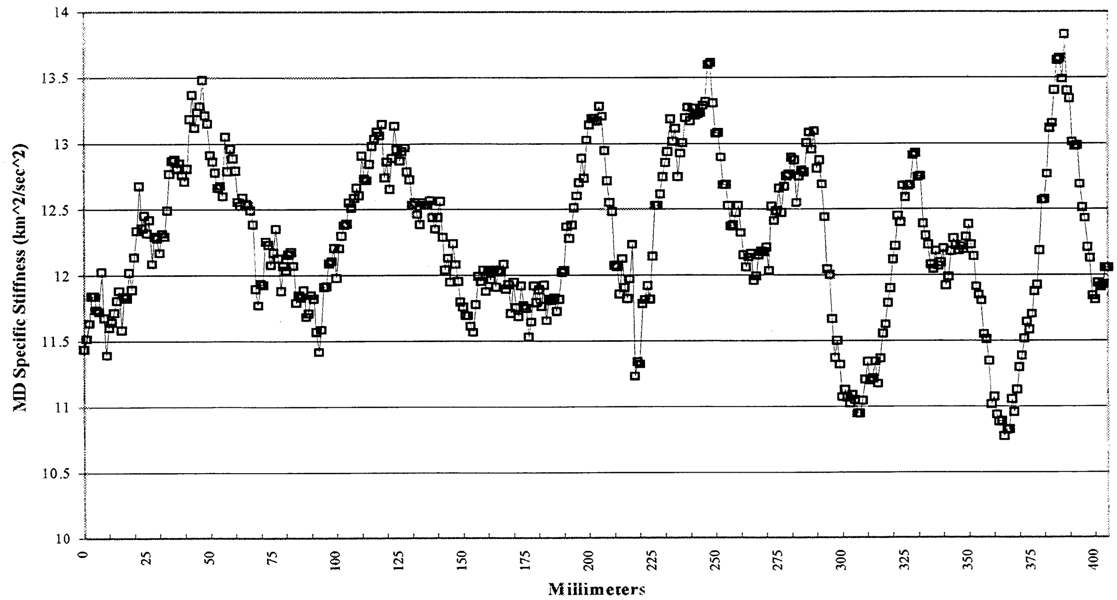

Figure 1. MD Specific Stiffness at 1-millimeter CD intervals on a 40-cm segment of a 80 g/m^2 kraft CD strip.

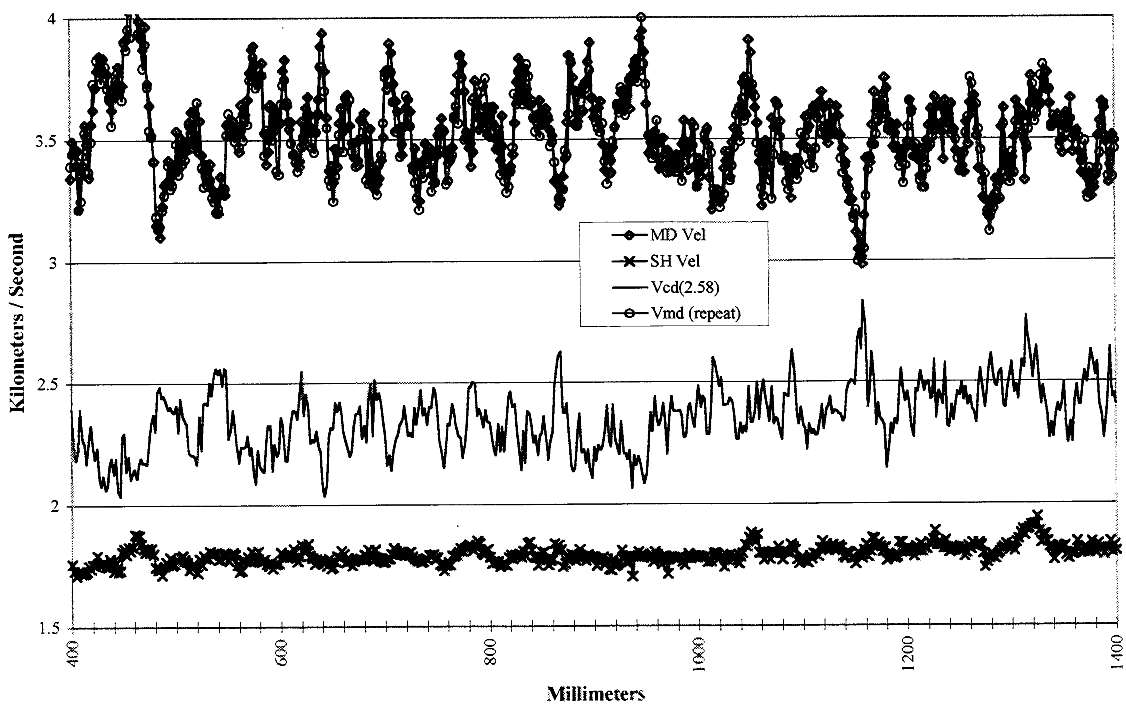

Figure 2. MD longitudinal velocity, MD shear velocity, and calculated CD longitudinal velocity at 2-millimeter CD intervals on a 1-meter segment of a 80 g/m^2 kraft CD strip.

ZD MEASUREMENT SYSTEM

Fluid-filled wheels containing ultrasonic transducers are used commercially in testing railroad rails for flaws. Similar wheels have been modified and adapted for our application. The paper runs in the nip between one wheel above the web and one wheel below. Ultrasonic pulses are transmitted from a transducer in one wheel through the paper to a transducer in the other wheel. Comparisons of the arrival times of echo and transmitted pulses with and without the paper web in the nip provide measurements of the transit time and caliper.

In order to evaluate the sensor measurements on moving webs in the laboratory, an unwind/rewind web handling system was designed and purchased. This IPST web handling system includes a web guide and a splicing station. It can operate at speeds up to 750 meters per minute, running in either an endless loop or a reel-to-reel mode. A dancer arm provides adjustable tension in the loop mode, and tension is automatically controlled in the reel-to-reel mode. The system is able to handle webs up to 35 centimeters in width as 12-meter endless loops or as reels up to 90 centimeters in diameter.

A test stand for mounting the fluid-filled wheels was designed and constructed to operate with the web handling system. The wheel mounts are extended and retracted by air cylinders. Motors are provided to drive the wheels to match the web speed before and after closing the wheels onto the web. The wheel axle spacing (nip pressure) is adjustable.

A caliper measurement is required along with the transit time through the sample in order to calculate the ZD velocity of ultrasound. Either multireflected ultrasonic pulses in the fluid-filled wheels or an independent caliper gauge may be used to determine the web caliper. The main advantage of an independent gauge is that less data processing is required. The principal advantage of the use of the multireflected pulses is that the data are collected at the same sample locations and with the same sample compression as the transit time data.

Figure 3 shows the ZD ultrasonic transit time for a CD strip of 205 g/m^2 liner. The 6.6-meter CD strip was spliced with other paper to make a continuous loop 12 meters in length. The transit time was recorded 50 times a second. With the web moving at 15 meters per minute (25 cm/second), a reading is obtained every 5 millimeters. Figure 3 presents data recorded in this way for two passes of the CD strip. The time scale in nanoseconds for Pass #1 (the upper plot) is on the left, and the time scale for Pass #2 (the lower plot) is on the right. The plots are offset to enable one to visually judge the repeatability.

To further demonstrate the repeatability of the measurements, Figure 4 presents the comparison of Pass #1 and Pass #2 for a 24-cm section of the CD strip using the segment of the data ending at the 100-cm mark of Figure 3.

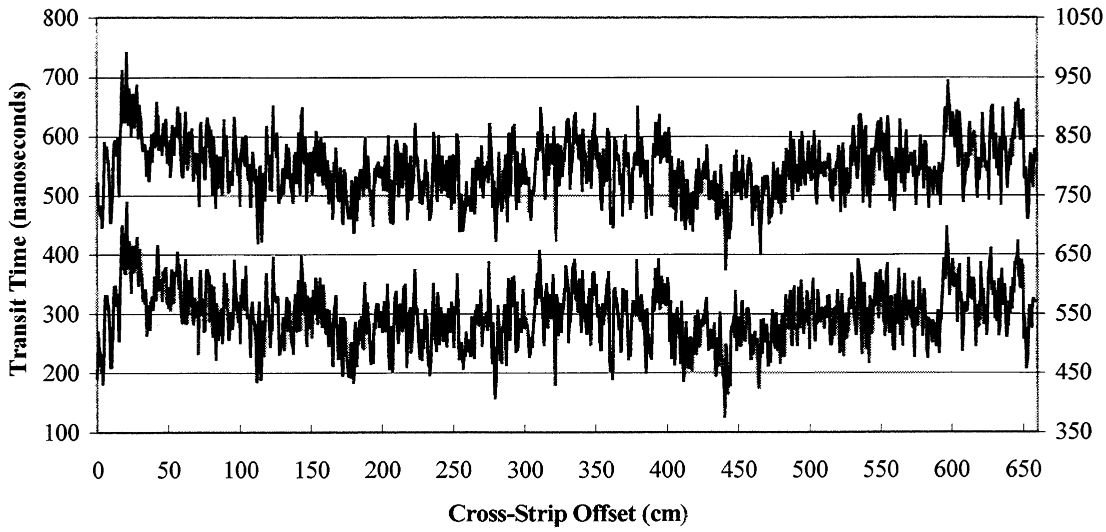

Figure 3. ZD ultrasonic transit time for a CD strip of 205 g/m^2 liner. The time scale for Pass #1 (the upper plot) is on the left, and the time scale for Pass #2 (the lower plot) is on the right. The plots are offset for visual comparison.

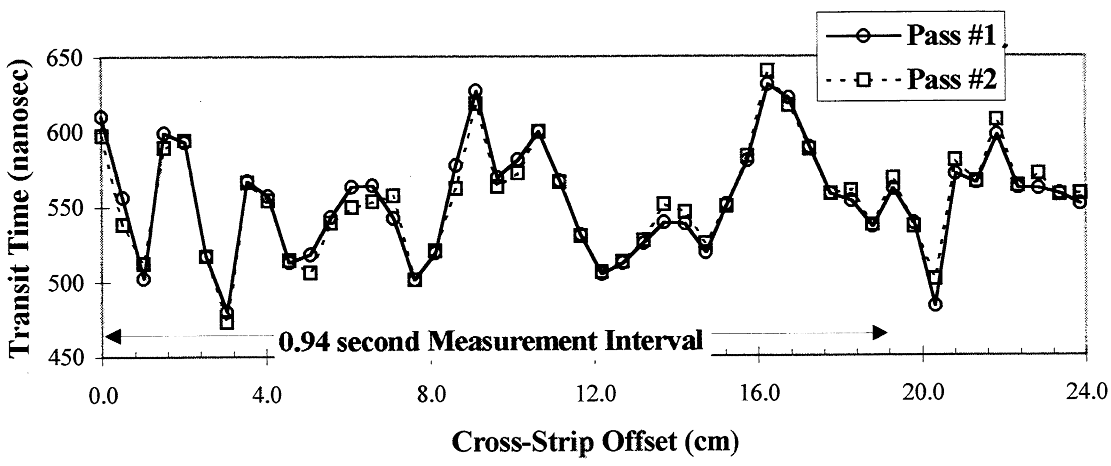

Figure 4. ZD ultrasonic transit time measurements over a 24-cm section of a 205 g/m^2 liner CD strip. Comparison of two passes to illustrate repeatability.

BASIS WEIGHT MEASUREMENT

An AccuRay® 1190™ System with a Smart Platform™ 1200 has been installed on the web handling system in the IPST laboratory. The sensor carriage on the scanner contains state-of-the-art basis weight, moisture, temperature, and caliper sensors. Hardware and software have been developed to collect measurement data at a high sampling rate directly from the sensors in the scanner. This can be used to log high resolution data for machine-direction rolls or cross-direction strips. CD strips or smaller samples may be spliced as part of a 12-meter belt on the web handler. For a web moving at 15 meters per minute (25 cm/second), a sampling rate of 250 measurements per second provides a reading every millimeter.

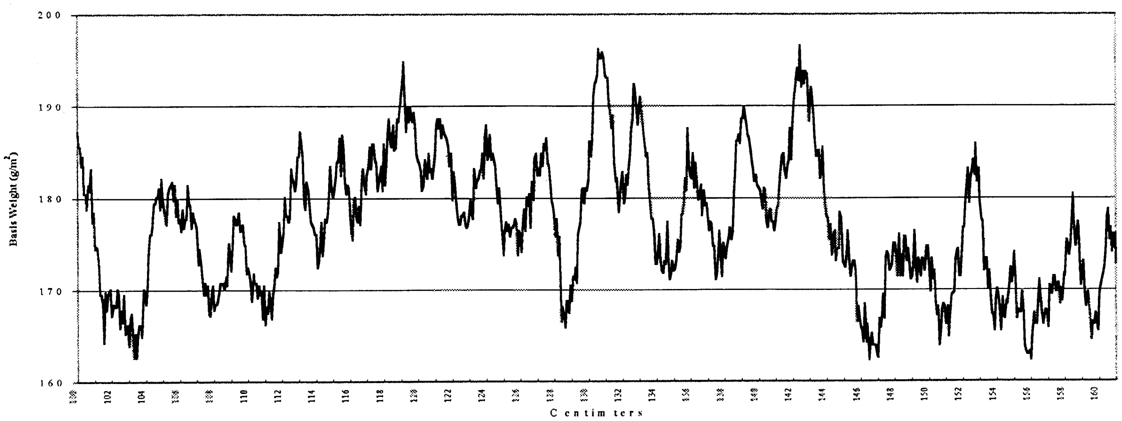

Figure 5. Basis weight of 60-cm section of a CD strip at a resolution of 13 points/cm.

SUMMARY

The ability to measure basis weight, caliper, ZD transit time, and in-plane ultrasonic velocities at high resolution is being used as a research tool to evaluate paper properties and their relationship to the papermaking process. These measurements are repeatable and show large short-range variations in the properties of typical machine-made paper samples. Evaluation of the potential relationships of the measured short-range variations in CD strip properties to the nonuniformities, streaks, and "dry-line fingers" observed on the forming table [3] continues.

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Contact point: Maclin S. Hall, Institute of Paper Science and Technology, 500 10th Street, N.W., Atlanta, GA 30318-5794 - USA, Phone 404/894-5733, Fax 404/894-4778, E-mail: mhall@ipst.edu